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DESIGN AND FABRICATION OF AN AEROSOL CONCENTRATOR.(U)
MAY 80 R K STILLING, H E GERBER
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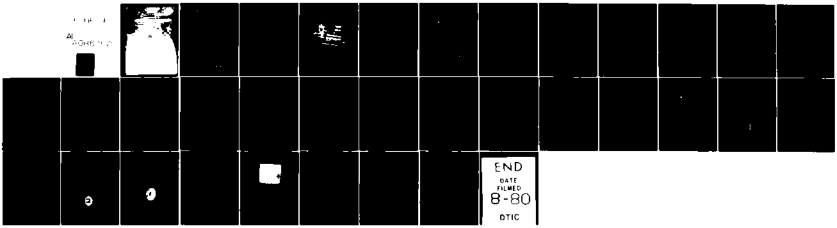

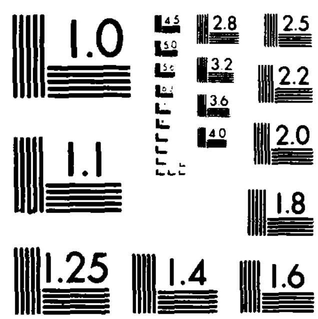
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An aerosol concentrator used in conjunction with a folded-path transmissometer, was designed and fabricated at NRL. The concentrator extends the effective length of a laser beam used in the transmissometer by more than one order of magnitude by concentrating the particles in the ambient aerosol by a like amount. This report reproduces engineering drawings and describes the fabrication of the concentrator. Problems encountered during the fabrication and testing procedures are also discussed.

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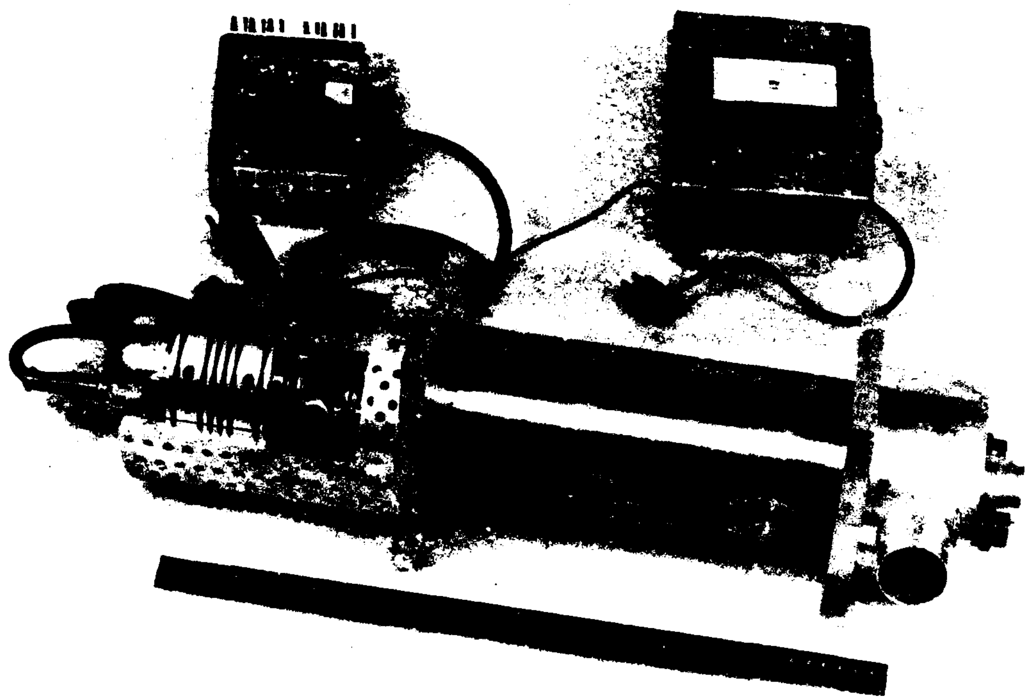

Fig. 1—The aerosol concentrator

DESIGN AND FABRICATION OF AN AEROSOL CONCENTRATOR

INTRODUCTION

An aerosol concentrator was developed to operate in conjunction with a folded-path transmissometer, both of which were designed and fabricated here at NRL [1]. The concentrator extends the theoretical length of a laser beam used in the transmissometer by concentrating the particles in the aerosol by more than one order of magnitude. In this report engineering drawings are reproduced, and the fabrication of the concentrator is detailed. Problems encountered and important manufacturing and testing details are described.

The aerosol concentrator (Fig. 1) increases the concentration of the dispersed phase of ambient aerosol without affecting the portion of the particle-size distribution which influences light scattering and absorption. In introducing the concentrate into a folded-path light cell, the optical coefficients are scaled up by a factor equivalent to the concentration increase over ambient values.

The concentrator is similar in design to those built by Shutte [2], Budinsky [3], and others. It differs in that it can concentrate significantly smaller particles and in that its geometry minimizes internal particle losses. It functions as follows (Fig. 2): Ambient aerosol flows at a rate V_1 (250 liters per minute) into the inlet manifold and along a concentric annulus formed by a solid outer cylinder at rest (radius $R_2 = 5.0$ cm) and a porous inner cylinder rotating at high speed (radius $R_1 = 4.4$ cm and length $L = 30$ cm). Suction applied at the right end of

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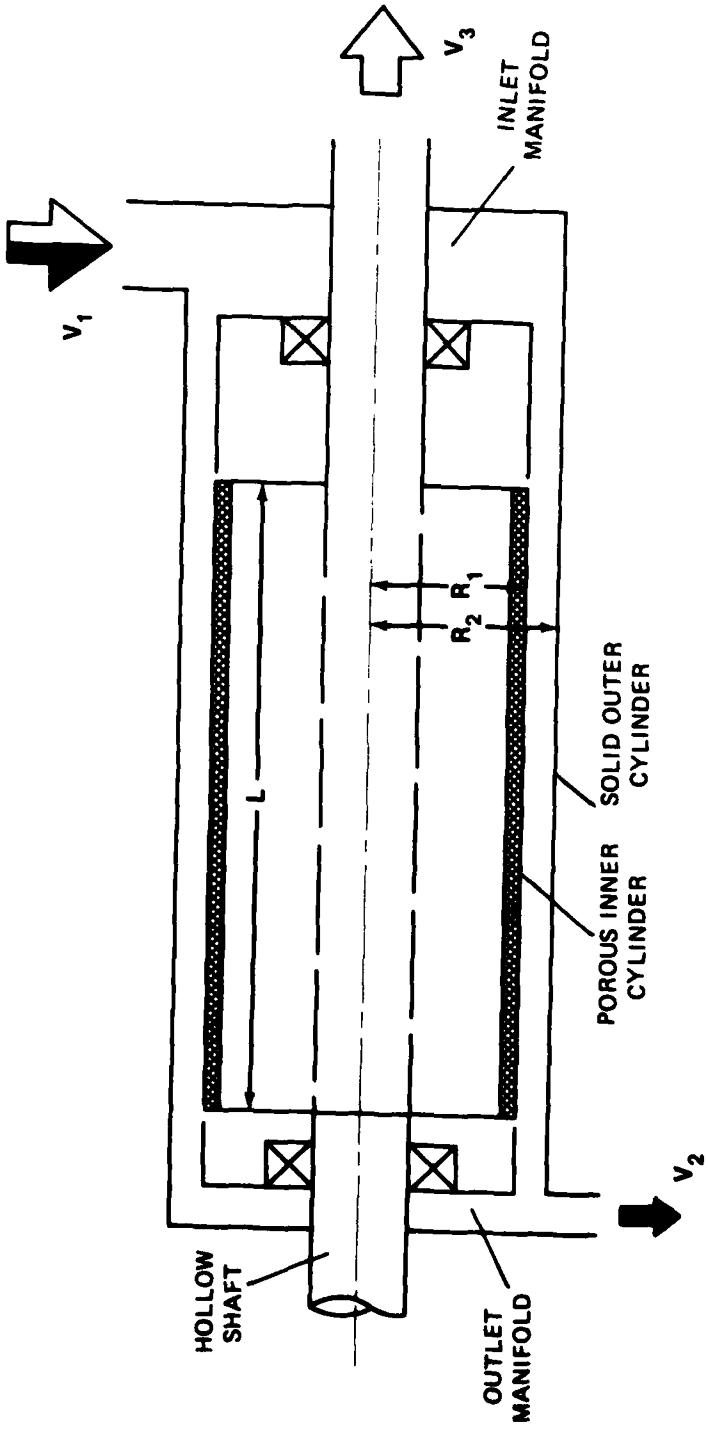


Fig. 2—Schematic of the aerosol concentrator

the hollow shaft causes the dispersion medium of the aerosol to pass through the porous cylinder and into the shaft at the rate V_3. Since the rotational velocity of the entrained aerosol particles is comparable to that of the rotating cylinder near its surface, the centrifugal force repulses the particles from the cylinder's surface as they move to the left in the annulus. The particles reach their highest concentration near the outlet manifold, where they are drawn off at a rate V_2 (10 liters per minute) for use with the folded-path light cell. Particle losses in the concentrator are due to inertial impaction on the outer wall and suction into the pores of the inner cylinder. The aerosol experiences negligible temperature and presssure changes while passing through the concentrator. Since the input flow rate of the aerosol is $V_1 = 250$ liters per minute and the concentrate flow rate is $V_2 = 10$ liters per minute, the expected concentration factor without particles losses is simply $V_1/V_2 = 25$.

The lower size limit of the particle bandpass in the aerosol concentrator is the size of particles that are drawn into the porous cylindrical rotor and become part of the volume flow rate V_3 of the dispersion medium being removed instead of the volume flow rate V_2 of the aerosol concentrate. This occurs when the particles' Stokes velocity due to the centrifugal force created by the spinning rotor is less than the mean suction velocity into the rotor. Thus the size limit is found by equating those two velocities:

$$\frac{D^2\rho\omega^2R_1}{18\eta}\left[1 + \frac{2\lambda}{D}\left(A + Be^{-CD/2\lambda}\right)\right] = \frac{V_1 - V_2}{2\pi R_1 L},$$

where D is the diameter of a spherical particle with density ρ, R_1 is the radius of the rotor, L is the length of the rotor, ω is the angular velocity of the rotor, λ is the mean free path of air, η is the viscosity of air, and A, B, and C are slip corrections usually assigned the values 1.246, 0.42, and 0.87 respectively.

The upper size limit is difficult to determine theoretically, since it is partially a result of turbulent impaction losses. However, a best case can be calculated for "stirred settling" losses [4] in a chamber of size R_1 and L.

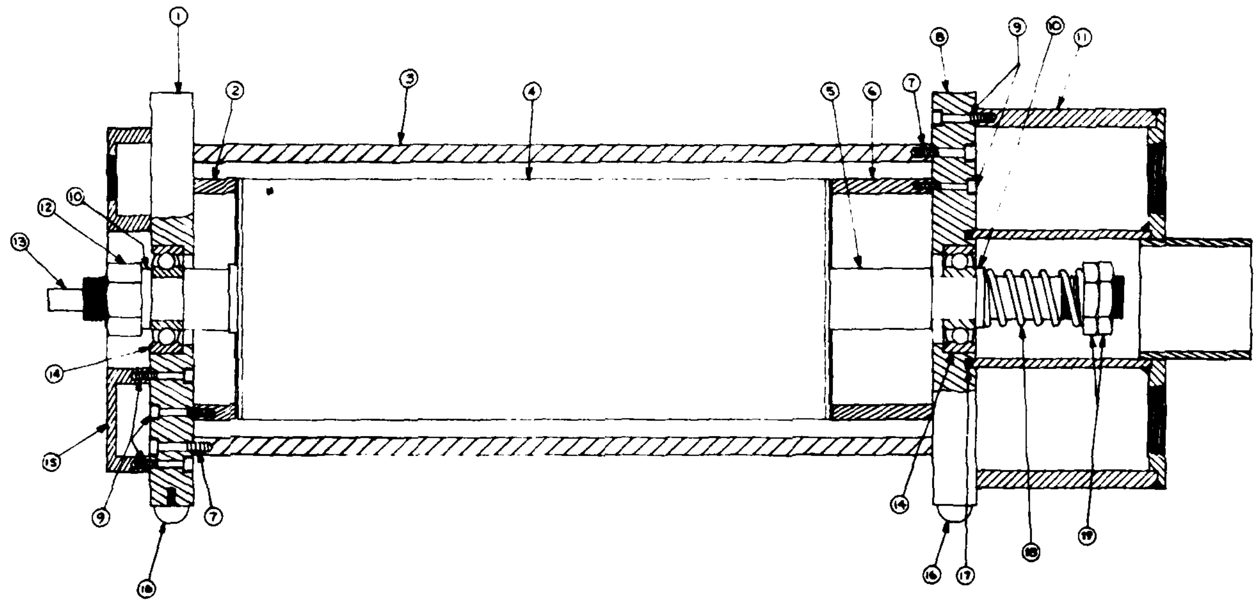
FABRICATION OF THE CONCENTRATOR

Figure 3 is a cutaway drawing of the assembled concentrator. Drawings of the individual parts numbered in Fig. 3 are in the appendix, with Fig. A1 in the appendix showing part 1, Fig. A2 showing part 2, etc. In the following subsections, in the order in which the parts are numbered in Fig. 3, we discuss details of each part and describe any problems we encountered during fabrication.

Part 1: Exhaust End Plate

The exhaust end plate (part 1 in Fig. 3 and shown separately as Fig. A1) serves several functions: It houses one of the two bearings (part 14) supporting the rotating filter shaft (part 5). It holds and locates a filler ring (part 2). It supports the exhaust manifold (part 15). It supports and locates the outer housing (part 3).

The end plate is machined from 6061-T6 aluminum plate originally having a nominal thickness of 19 mm (3/4 in.). The plate is squared to a finished dimension of 152.4 by 152.4 mm (6 by 6 in.). Both sides are then fly cut to a finished dimension of 15.9 mm (5/8 in.). Then a center hole is bored in the plate to accommodate a shaft-support bearing (part 14), leaving a shoulder to act as a stop for the bearing. The hole should be bored for a light press fit of the bearing's outer housing. All other machining operations needed on the end plate are referenced to the center bore. Holes for locating the exhaust manifold (part 15), filler ring (part 2), and outer housing (part 3) are now machined, with the clearance of holes for the cap screws



1. EXHAUST END PLATE
2. FILLER RING - SHORT
3. OUTER HOUSING
4. POROUS FILTER - MOTT METALURGICAL CORP. #SK-530
5. ROTATING FILTER SHAFT
6. FILLER RING - LONG
7. 6-32 × 3/8" ST. STEEL ALLEN CAP SCREW - 12 REQUIRED
8. INTAKE END PLATE
9. 4-40 × 3/8" ST. STEEL ALLEN CAP SCREW - 30 REQUIRED
10. WASHER
11. INTAKE MANIFOLD
12. 3/8-16 ST. STEEL NUT
13. DRIVE SHAFT
14. BEARING - BARDEN PRECISION #203FFT
15. EXHAUST MANIFOLD
16. RUBBER FOOT WITH 6-32 × 1/4" SCREW
17. "O" RING - PARKER 2-224
18. SPRING
19. 3/8-16 ST. STEEL JAM NUT

Fig. 3—Assembly drawing of the aerosol concentrator

being kept to a minimum, because these screws are all that keeps everything concentric. Next the 20 concentrate-feed holes (shown in Fig. A1 but not seen in Fig. 3) are drilled. Finally a suitable pair of rubber feet (part 16) should be installed on the bottom edge of the end plate to minimize any vibration induced by other equipment or by the concentrator itself.

Part 2: Filler Ring

The filler ring (part 2), which is fastened to the end plate and functions as a fairing to reduce turbulence at the exhaust end of the concentrator, is machined from 318-type stainless steel. A clearance of between 0.05 mm (0.002 in.) and 0.13 mm (0.005 in.) is maintained between the filler ring and the porous filter (part 4).

Part 3: Outer Housing

The outer housing (part 3) supports the end plates, contains the aerosols during concentration, and is a scatter shield should the rotating filter (part 4) fatigue and separate. We used a commercially supplied 10-cm-diameter (4-in.-diameter) schedule-40 type-304 stainless-steel seamless pipe. Nominal dimensions as furnished were 11.4 cm (4.5 in.) for the outside diameter and a wall thickness of 6 mm (0.237 in.). We set up the piple in a lathe and took a skim cut on the outside to clean up the surface so that the pipe could be run in a steady rest. The inside was rather irregular and had to be bored and polished to avoid any turbulence during concentration of the aerosol. Clearance between the rotating filter (part 4) and the outer housing does not seem to be critical, but concentricity should be maintained so that flow will be laminar during operation.

Next the ends are machined, with care taken to make the ends parallel to each other and perpendicular to the bore of the housing. If the ends are not parallel, early bearing failure will result, because the housing is the only link between the end plates.

Finally the holes for the mounting screws are drilled and tapped. The holes at each end of the housing should be in the same plane, so that the end plates will sit evenly on their feet.

Part 4: Porous Filter

The porous filter (part 4) is the heart of the system. This filter was custom made for the concentrator by the Mott Metallurgical Corporation of Farmington, Connecticut. The filter is a sintered sleeve made up of stainless-steel particles which have been sifted through a number-200-mesh screen to ensure uniform porosity. Roughly 1/5 of the cylindrical surface area consists of pores, with an average diameter of 25 μm. The tensile strength of the filter material has been calculated to withstand centrifugal forces up to 25,000 rpm. The cylinder was bored on the inside and turned and ground on the outside, after which it was chemically etched to reopen the pores that were closed during the machining.

Part 5: Rotating Filter Shaft

The rotating filter shaft (part 5) was furnished by the Mott Metallurgical Corporation along with the rotating filter as an assembly. Specifications for a suitable shaft required some experimentation. At first we used a piece of stainless-steel double-wall seamless pipe. One problem we encountered resulted from the diameter of the pipe not being kept concentric with the inside diameter during fabrication. The problem was that stress relief brought on by the machining made warping of the pipe almost unavoidable.

Assembly of a prototype filter shaft also revealed other problems in what was thought to be good machine-shop practice. We assembled two parts; one was the porous filter with end plates heliarced to it, and the other was the shaft with all machining done except the final grinding in the area for shaft bearings. Our assembly method was to heat the filter part and freeze the shaft, resulting in a slip fit during assembly and an interference fit after the two parts attained equal temperature, with the interference fit sealing all joints for air tightness and ensuring that the filter and shaft would turn as one part. During the mating of the parts, however, the closeness of the fit caused the slip fit to end sooner than expected as equilibrium was approached, requiring a pressing to finish getting the parts into their proper location. The end result was stress and warping of the shaft and filter. Although the machinist was able to clean up the outer surfaces so as to be concentric, the wall thickness of the porous filter was then not uniform. We later found this caused two problems: the filter assembly was impossible to balance as speed increased, due to centrifugal distortion, and unequal suction through the filter caused turbulent flow through the concentrator.

The second and satisfactory method of assembly that we tried was to make all the parts separately, press them together using only light pressure, and lock the parts with a chemical locking agent to ensure that the parts would rotate and stay in the same relative position during use. Maintaining the same relative position is required for proper balance. The balancing process will be described in the final main section.

Part 6: Filler Ring

Part 6 is a filler ring similar to part 2.

Part 7: Number-6 Allen-Head Cap Screws

The fasteners used (parts 7 and 9) are off-the-shelf Allen-head stainless-steel cap screws. Number-6 screws (part 7) are used where major components are connected and where high stress could appear due to malfunctions. Number-4 screws (part 9) are used where filler rings and manifolds are fastened.

Part 8: Intake End Plate

The intake end plate (part 8) is identical to part 1 except for the mounting holes, the 0-ring groove, and the size and number of through holes for aerosol flow.

Part 9: Number-4 Allen-Head Cap Screws

Part 9 was described in conjunction with part 7.

Part 10: Washers

The two washers (part 10) are machined from stainless-steel stock. The ends must be parallel to avoid unequl pressures on the inner bearing races, and the inside diameter must be large enough for free movement on the shaft.

Part 11: Intake Manifold

The intake manifold (part 11) consists of three aluminum parts heliarced together. It is machined and drilled for the mounting screws. Three ports are incorporated: the central port for the suction which pulls the air through the filter and out the end of the hollow shaft and two ports in the outer chamber, one for intake of the aerosol and the other for intake from a clean-air source to purge the concentrator.

Part 12: Nut

Part 12 is a 5/8-18 standard stainless-steel nut. The surface which seats against the washer is skim cut to be perpendicular to the shaft axis.

Part 13: Drive Shaft

The drive shaft (part 13) is a stainless-steel plug pressed into the aerosol-exhaust end of the rotor shaft, making the end of the shaft airtight and providing a place to attach the drive motor. The plug is machined to a diameter of 8 mm (5/16 in.) to mate with a flexible coupling used in line with the motor.

Part 14: Shaft Bearings

For shaft bearings (part 14) precision ball bearings were chosen because of their close tolerances and low friction. The bearings used were manufactured by the Barden Precision Bearing Corporation of Danbury, Connecticut. The model 203FFT bearing was used, which is a deep-groove radial bearing with double seals made of a fibrous material backed by an aluminum shield to retain the lubricant and keep out contaminants. The seals are designed to minimize seal friction. The bearing also incorporates a low-friction ball cage.

Originally a problem arose with the use of these bearings. Vibrational frequencies were transmitted throughout the concentrator at certain speeds and would have eventually destroyed the bearings. Our solution was to preload the bearing with a coiled compression spring (part 18). A 111-newton (25-pound) force against one washer loads the inner race of the adjacent bearing and in turn is transmitted through the shaft to load the inner race of the other bearing. With this force eliminating any radial play in the bearings, the concentrator ran extremely smooth.

Part 15: Exhaust Manifold

The exhaust manifold (part 15) is fabricated from a solid piece of 6061-T6 aluminum. In the face of the manifold a hole is drilled and tapped for a 9.5-mm (3/8-in.) pipe fitting which is used to draw off the concentrate.

Part 16: Rubber Feet

The two pairs of rubber feet (part 16) are attached with 6-32 1/4-in. screws or any other size of screws found appropriate for whatever pairs of feet are found suitable.

Part 17: *O*-Ring

Part 17 is a standard Parker 2-224 *O*-ring.

Part 18: Spring

The preload spring (part 18), which was discussed along with part 14, was made from 2.4-mm-diameter (0.093-in.-diameter) music wire and consisted of 7 turns with the ends closed and ground. The inside diameter should be about 0.1 mm (several thousandths of an inch) larger than the shaft, such that the spring can compress properly but not such that the runout is large enough to allow unbalance.

Part 19: Jam Nuts

The pair of jam nuts (part 19) are standard 5/8-18 stainless-steel nuts turned down to a thickness of 6.35 mm (1/4 in.). The nuts are turned down and then jammed against each other to adjust and then maintain the proper spring tension.

DRIVE MOTOR, MOTOR ATTACHMENT, AND SPEED CONTROL

Needed to complete the assembly are a drive motor, a motor clamp such as shown in Fig. A20 to fit the motor, a motor mount such as shown in Fig. A21 to be attached to the exhaust end plate, a flexible coupling, an electronic tachometer, and a variable speed controller. Our motor is a hand-held router motor, model 90114, manufactured by the Stanley Power Tool Company (P.O. Box 2217, West New Bern Station, New Bern, NC 28560). This motor is rated at about 0.2 kilowat (1/4 horsepower) at 12,000 revolutions per minute. It has proved satisfactory and runs with very little vibration. As a backup motor we have a Stanley model 91260, which is larger and is rated at about 1.1 kilowatts (1-1/2 horsepower) at 16,000 revolutions per minute.

We fabricated the motor mount to be attached to the exhaust end plate from a piece of 152-mm-o.d. (6-in.-o.d.) aluminum pipe with a wall thickness of 15.8 mm (5/8 in.). We drilled holes through the pipe to cool the motor. The split motor clamp was fastened to the motor mount to allow use of either motor.

Our flexible coupling is a Lord model J-1211-1-9 rubber coupling bonded to two drive sleeves with one end bored to accept a 6.4-mm (1/4-in.) shaft and the other end bored to accept a 7.9-mm (5/16-in.) shaft. Such couplings can be obtained from Lordco Supply (Erie, PA 16505).

Since the concentrator is run at various speeds, we incorporated an electronic tachometer into the system. The sensor, which is mounted directly over the motor shaft, consists of an infrared light-emitting diode and a Darlington phototransistor. These parts are encapsulated in a package measuring 32 mm by 16 mm by 6.4 mm thick (1-1/4 in. by 5/8 in. by 1/4 in. thick).

The shaft directly under the sensor is segmented longitudinally into eight equal spaces alternately painted white and flat black. The information from the sensor is fed via cable to the electronics package, which also houses a dial-type meter calibrated in revolutions per minute. This photoreflective tachometer, model 929, is manufactured by the Richard-Lee Company (Box 724, New Providence, NJ 07974).

In conjunction with the drive motor a variable-speed controller is used. Our controller is a Lutron Powerdial model PD-100, which has a load output of 10 amperes in the variable AC mode.

BALANCING OF THE ROTOR ASSEMBLY

As we mentioned, we balanced the rotor assembly inhouse to ensure the best possible balance. The rotor had been balanced quite well by the manufacturer, but their equipment will only allow a maximum speed of 1800 revolutions per minute. A slight unbalance was detectable at speeds over 5000 revolutions per minute.

Our method of fine tuning the rotor is to balance it in such a way as to duplicate the actual mode of operation. The only change made to the concentrator during the balancing is to replace the outer housing (part 3) with three 13-mm-diameter (1/2-in.-diameter) rods machined to the exact length of the housing and drilled and tapped at the ends to be attached in the same way as the housing. This exposes the rotor so that weights can easily be attached to the ends of the rotor with quick-set epoxy cement.

The instrument we used for the balancing is the Mechanalysis model 350 vibration analyzer and dynamic balancer made by IRD Mechanalysis, Incorporated (Columbus, OH 43229). This instrument consists of an electronic readout unit, vibration pickups, and a strobe-light tachometer. The electronic unit collects information from the pickup units in the form of frequency and amplitude of vibration, which is read out on panel meters.

The pickup units are attached to specially-made vise-grip pliers, which are in turn clamped onto each end plate of the concentrator. A mask has to be fabricated and divided into increments equaling 360 degrees and fastened so as to be stationary, with the shaft rotating in its exact center. A reference mark has to be painted on the shaft. The strobe light will stop-action the mark at some degree mark on the mask for each pickup unit as they are switched at the electronic unit. With this information in conjunction with the weight and location of trial weights epoxied on the ends of the rotor, a two-plane calculation can be made, giving the exact permanent location and weight needed to minimize any unbalance.

REFERENCES

1. H. Gerber, "Feasibility of Shipboard Laser-Attenuation Measurements with a Portable Transmissometer," NRL Report 8290, Feb. 26, 1979.

2. A.H. Shutte, "Filter apparatus," U.S. Patent 3,262,573, 1976.

3. K. Budinsky, "Rotating centrifugal separator with continuous dust removal," Staub 30, 7-13 (1970).

4. C.N. Davies, "Deposition from moving aerosols," pp. 393-446 in *Aerosol Science*, C.N. Davies, editor, Academic Press, New York, 1966.

Appendix A

VIEWS OF THE INDIVIDUAL PARTS

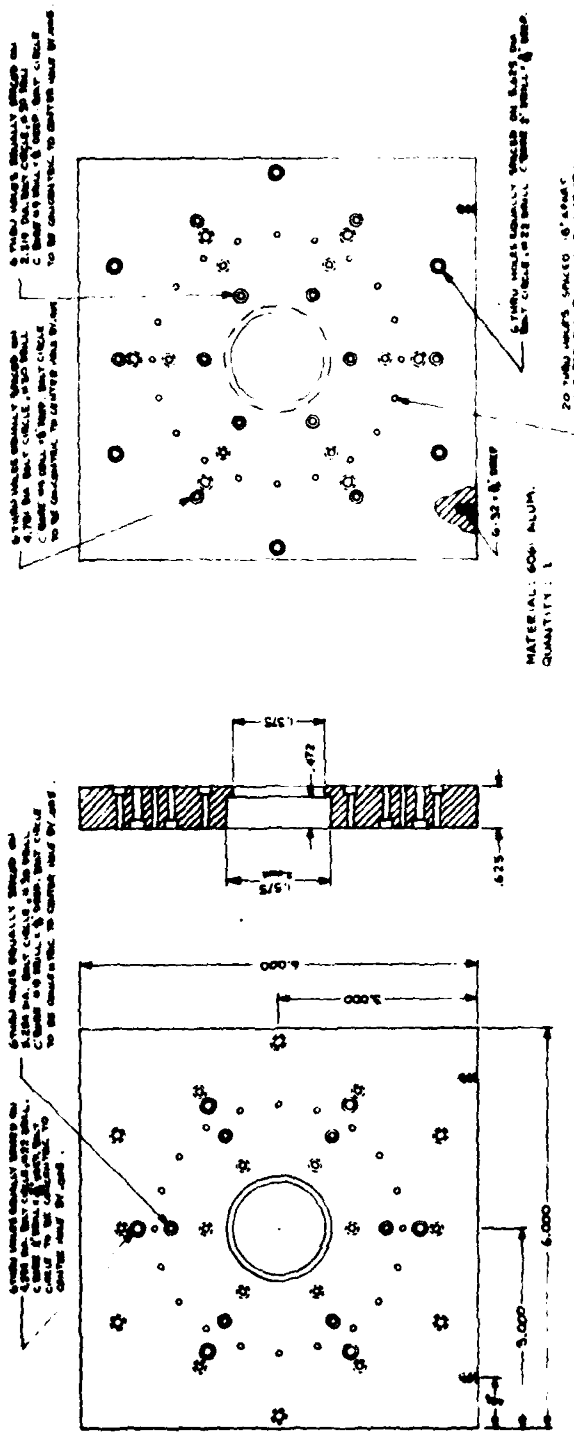
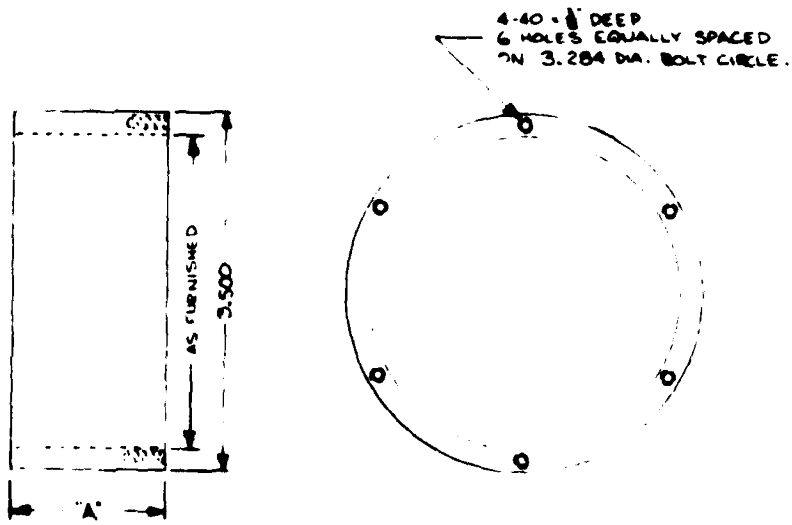


Fig. A1—Part 1 in Fig. 3, the exhaust end plate. Dimensions in this and subsequent figures are in inches; dimensions in millimeters can be obtained by multiplying by 25.4



MATERIAL : SCHEDULE 40 STAINLESS EXTRUDED SEAMLESS PIPE
QUANTITY: "A" - 1.490±.005 LONG, 1 PC.

Fig A2—Part 2: the short filler ring

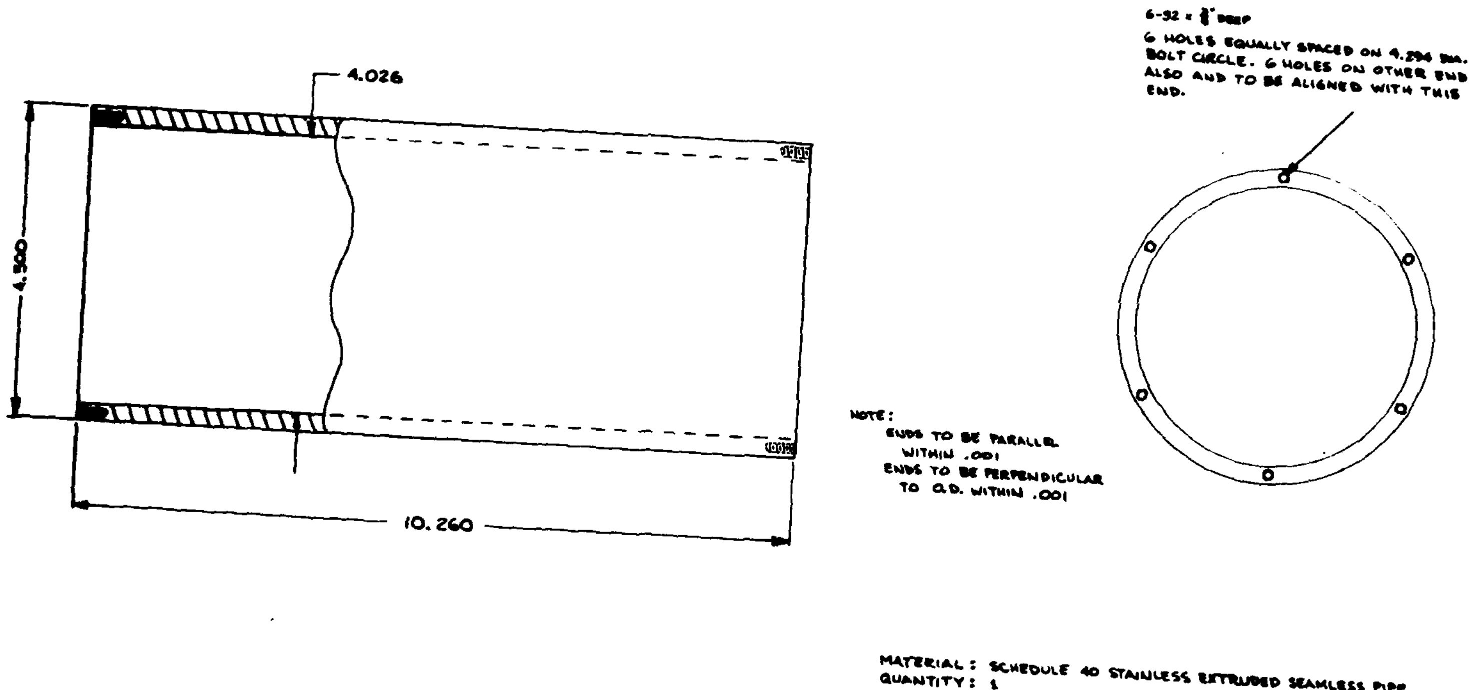


Fig. A3—Part 3: the outer housing

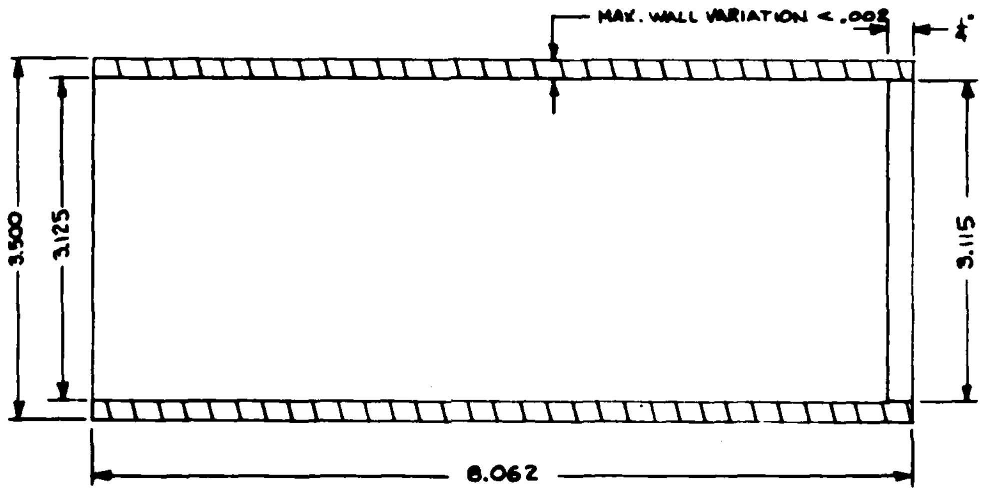
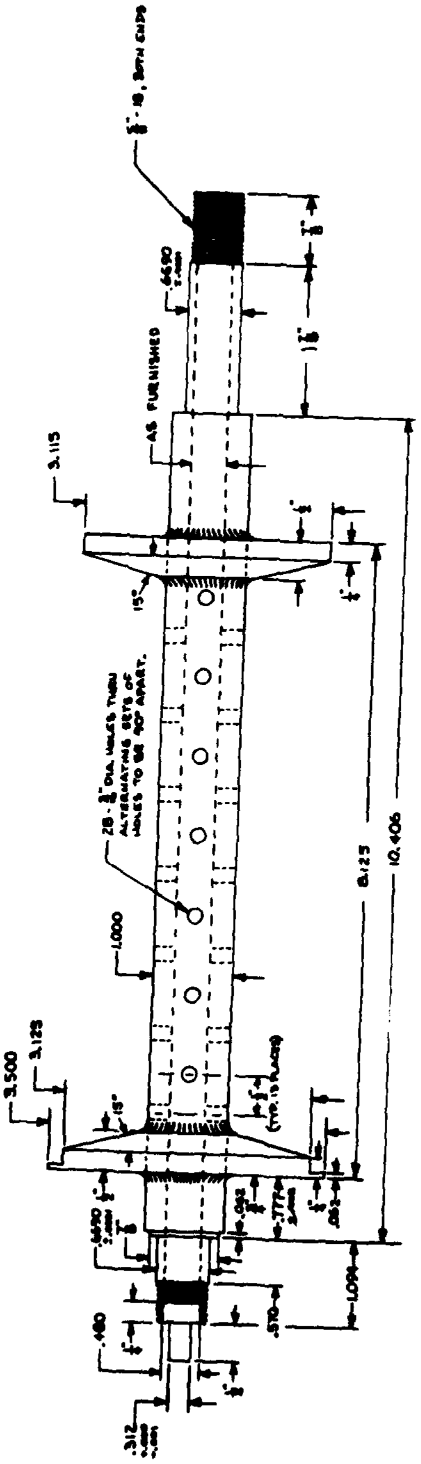


Fig. A4—Part 4: the porous filter



NOTES:

1. SHAFT AND END PLATE MATERIAL IS TYPE 304 STAINLESS STEEL. SHAFT IS FABRICATED FROM DOUBLE EXTRA HEAVY SEAMLESS 3/8" PIPE. FILTER IS MADE OF POROUS 316 STAINLESS STEEL.
2. MACHINE O.D. OF SHAFT BETWEEN CENTERS TO ENSURE EVEN WALL THICKNESS.
3. EACH END PLATE TO BE WELDED BOTH SIDES AND MACHINED AFTER WELDING. SEE NOTE 11
4. END PLATES TO BE ⊥ WITHIN .002 OF SHAFT.
5. SHAFT TO BE STRAIGHT WITHIN .001
6. BEARING SURFACES TO BE GROUND FOR CLOSE SLIDING FIT OF BEARINGS.
7. DRIVE PIN/PLUG TO BE MACHINED TO .312 [illegible] AFTER WELDING.
8. FILTER TO BE CLOSE SLIDING FIT ON END PLATES.
9. FILTER TO BE WELDED TO END PLATES.
10. OUTSIDE OF FILTER TO BE CONCENTRIC TO BEARINGS WITHIN .0003.
11. AN ALTERNATE METHOD OF SECURING THE END PLATES TO THE SHAFT IS USE A LIGHT PRESS FIT FOLLOWED BY CHEMICAL LOCKING SUCH AS LOCKTITE #601.

Fig. A5—Part 5: the rotating-filter shaft

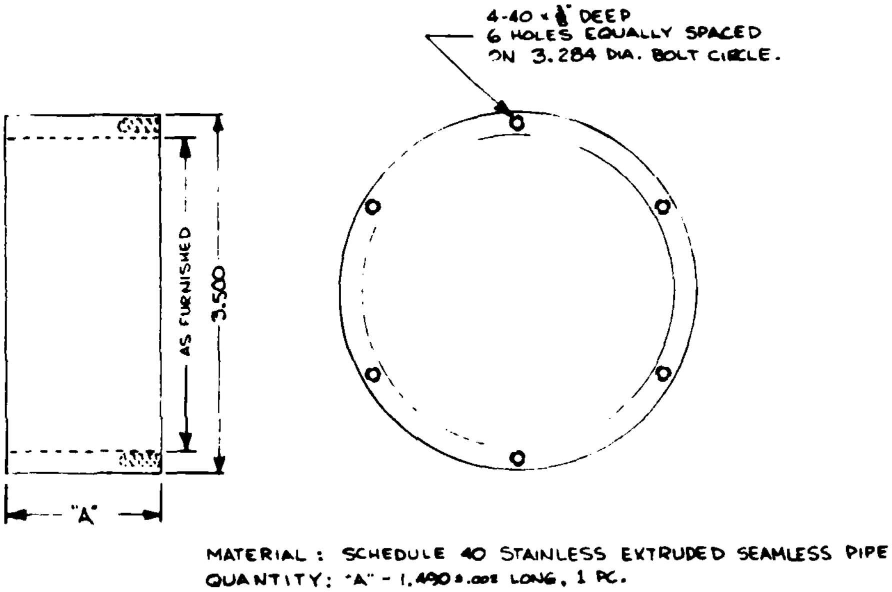


Fig. A6—Part 6: the long filler ring

Fig. A7—Part 7: a 6-32 by 3/4 in. stainless-steel Allen-head cap screw

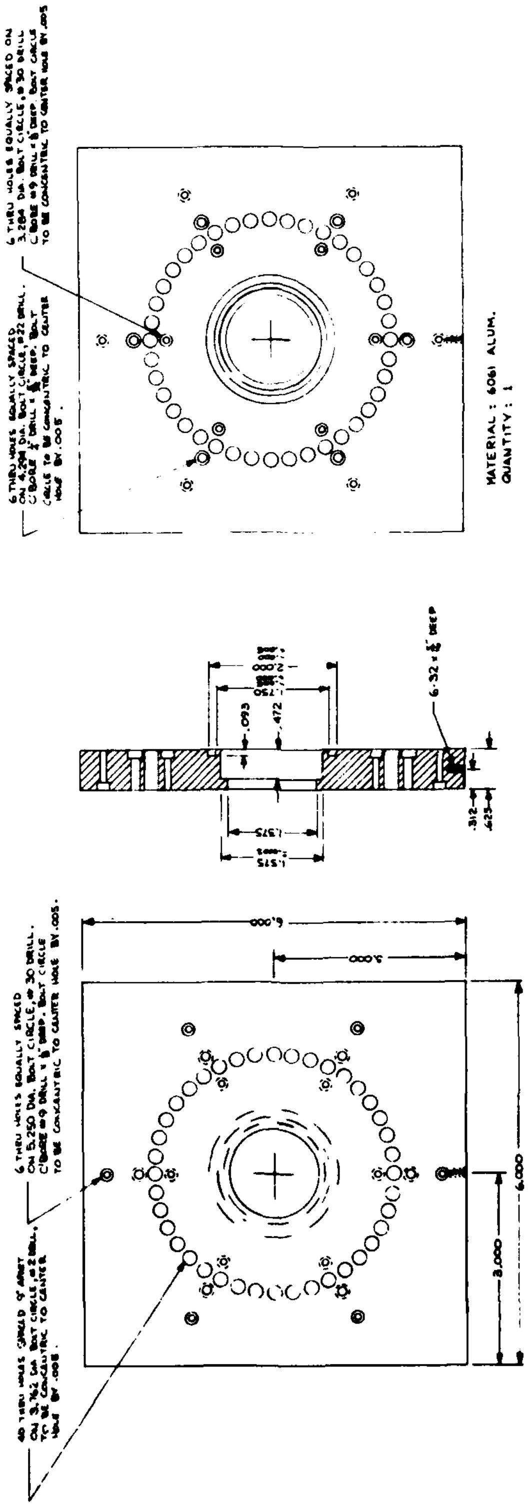


Fig. A8—Part 8: the intake end plate

Fig. A9—Part 9: a 4-40 by 3/4 in. stainless-steel Allen-head cap screw

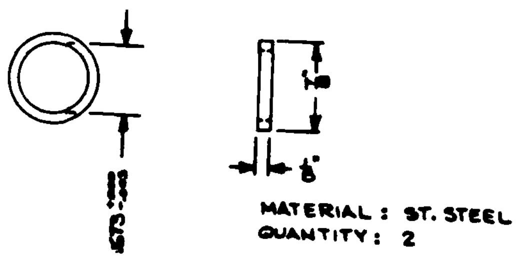


Fig. A10—Part 10: a washer

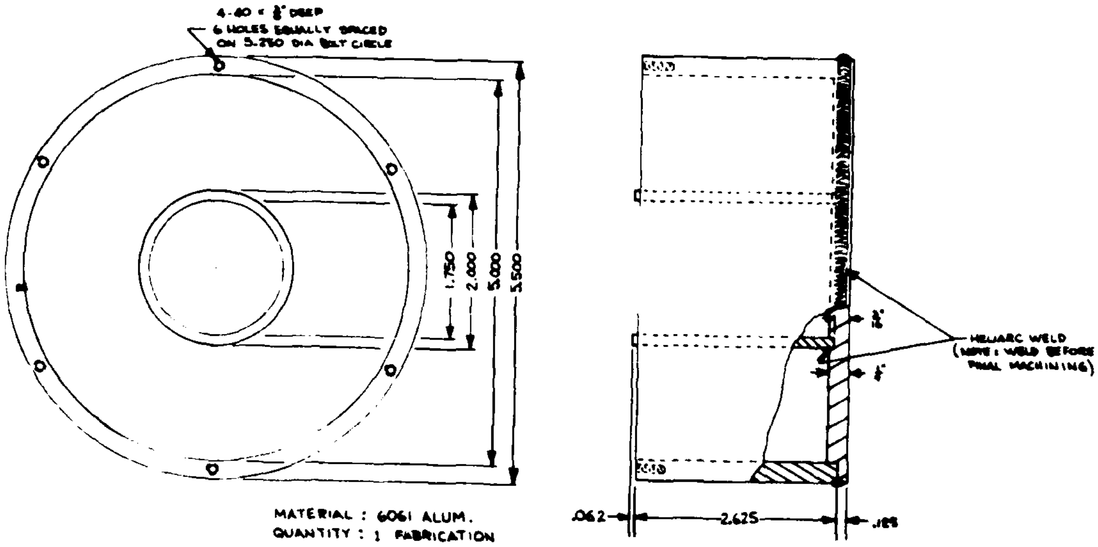


Fig. A11—Part 11: the intake manifold

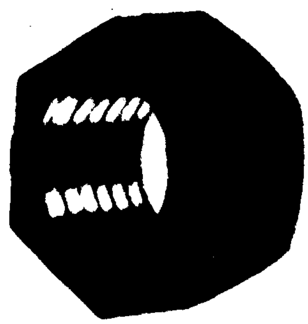


Fig A12—Part 12 the 5/8-18
stainless-steel nut

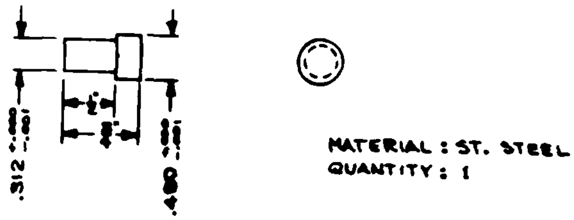


Fig. A13—Part 13: the drive shaft

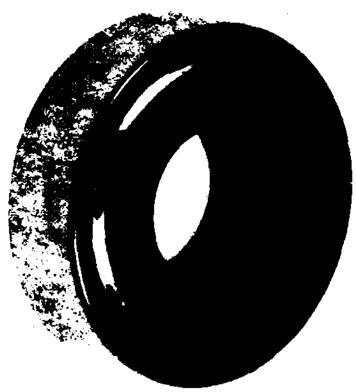


Fig. A14—Part 14: a shaft bearing

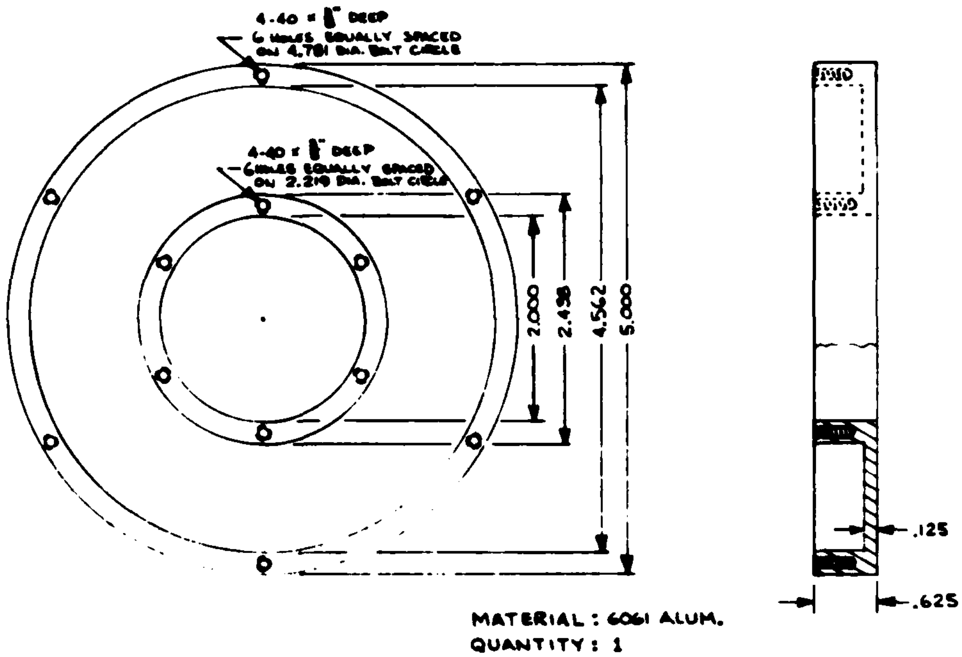


Fig. A15—Part 15, the exhaust manifold

Fig. A16—Part 16: a rubber foot

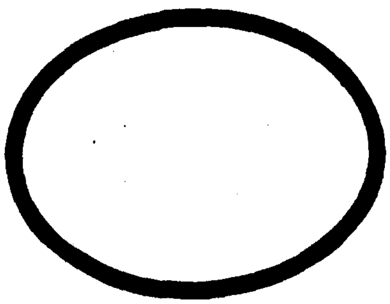


Fig. A17—Part 17: a Parker 2-224 O-ring

Fig. A18—Part 18: the spring

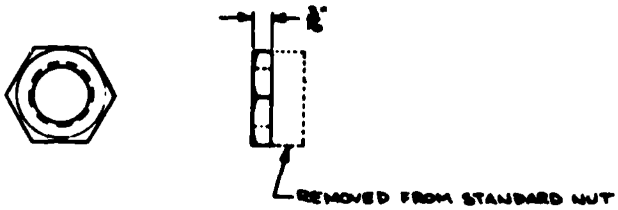


Fig. A19—Part 19: the pair of 5/8-18 stainless-steel jam nuts

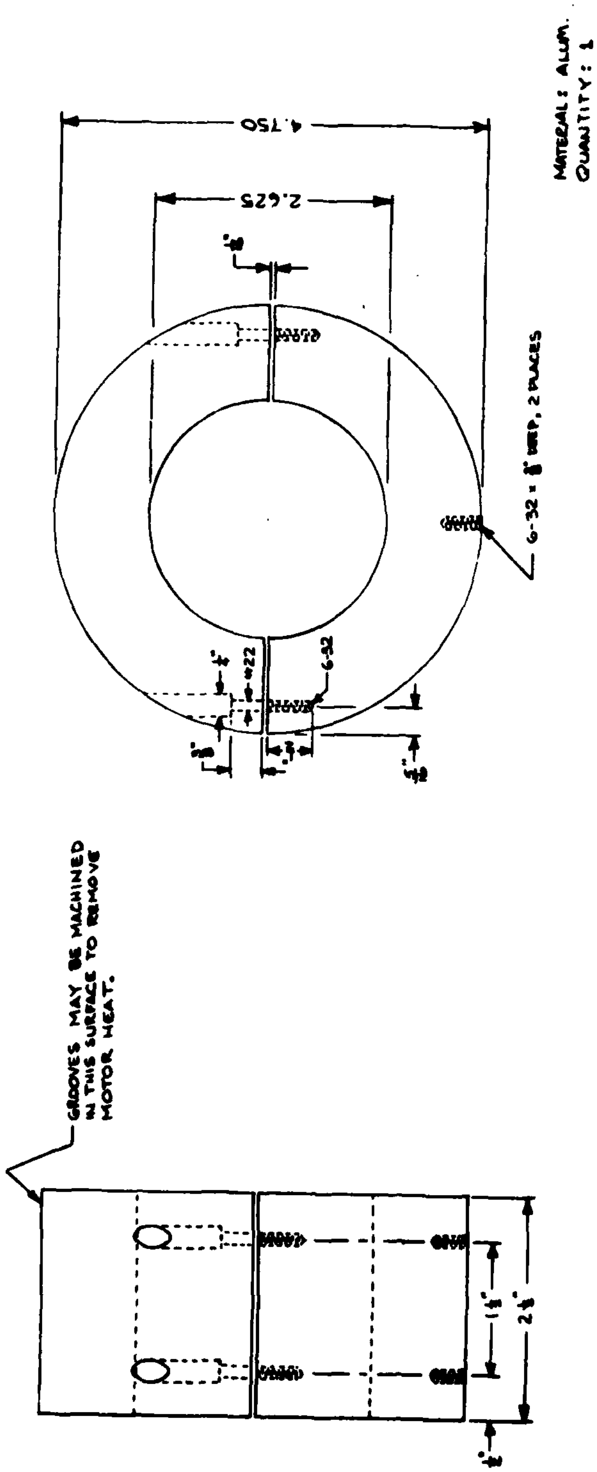


Fig. A20—Part 20: (not shown in Fig. 3): the motor clamp

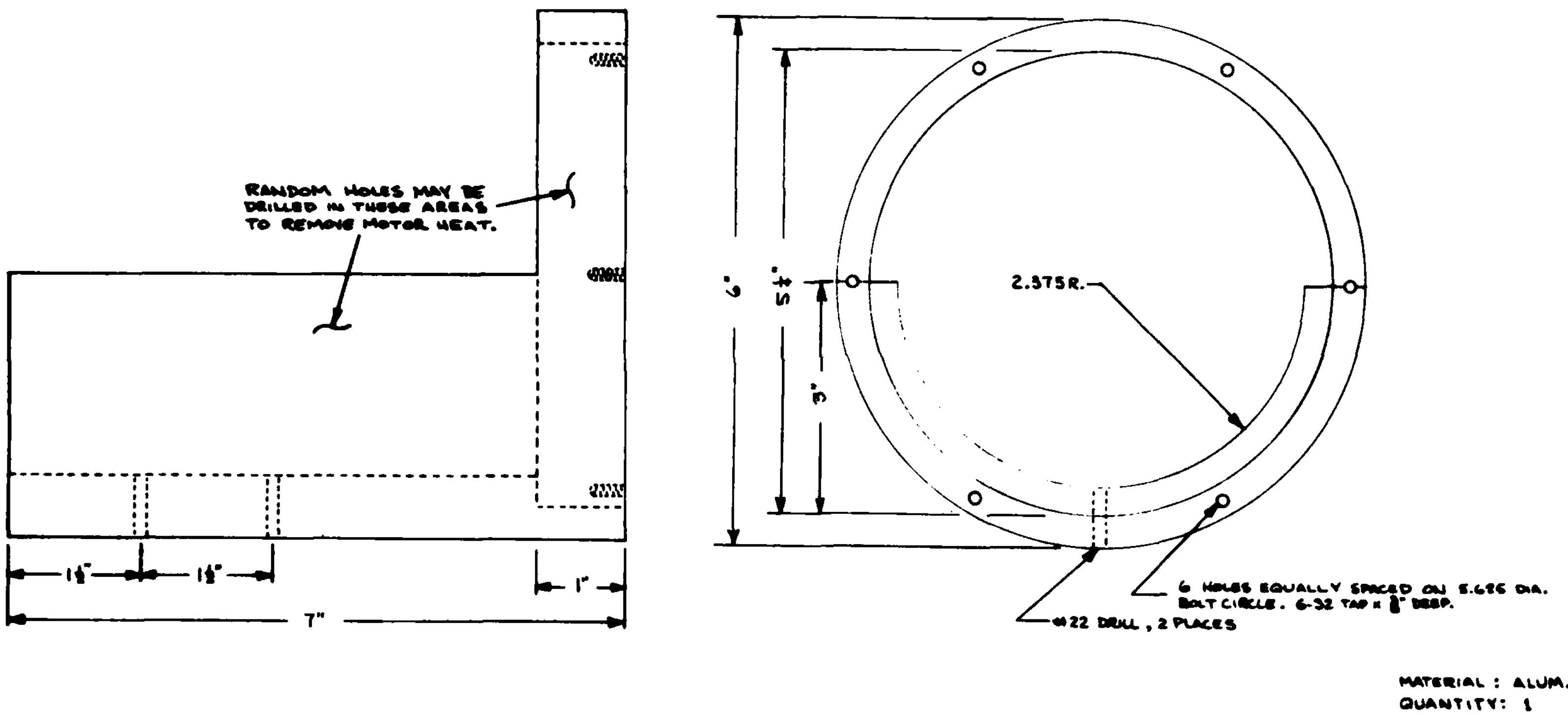


Fig. A21—Part21: (not shown in Fig. 3): the motor mount

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